



(19)

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(11)

EP 1 516 599 A2

(12)

## EUROPEAN PATENT APPLICATION

(43) Date of publication:  
23.03.2005 Bulletin 2005/12

(51) Int Cl.7: A61F 2/06, A61B 17/11

(21) Application number: 04028704.7

(22) Date of filing: 24.08.1999

(84) Designated Contracting States:  
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU  
MC NL PT SE

• Vanney, Guy  
Blaine, MN 55434 (US)

(30) Priority: 27.08.1998 US 141284

(74) Representative: Petri, Stellan et al  
Valea AB  
Box 4188  
203 13 Malmö (SE)

(62) Document number(s) of the earlier application(s) in  
accordance with Art. 76 EPC:  
99943852.6 / 1 107 710

Remarks:

This application was filed on 03 - 12 - 2004 as a  
divisional application to the application mentioned  
under INID code 62.

(71) Applicant: Percardia, Inc.  
Merrimack, NH 03054 (US)

(72) Inventors:

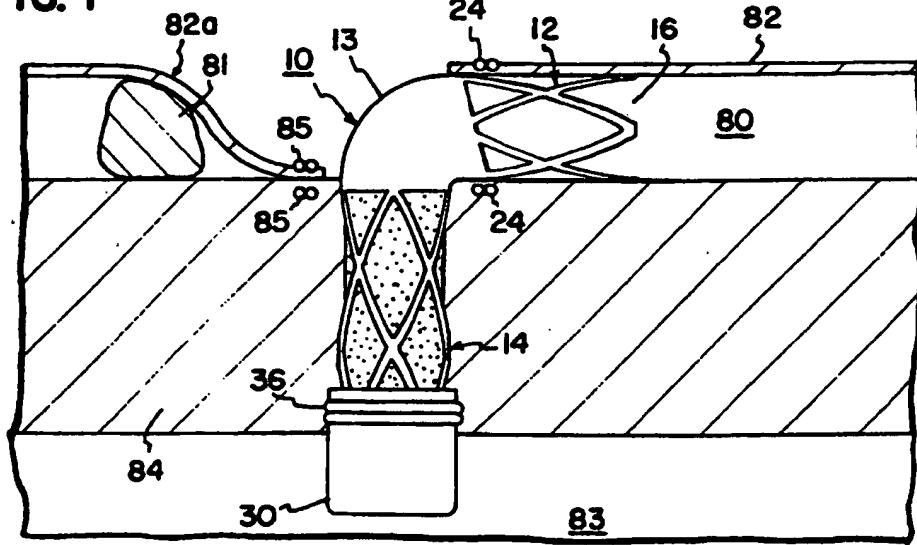
• Tweden, Katherine  
Mahtomedi, MN 55115 (US)

(54) A transmyocardial implant

(57) A transmyocardial implant for defining a blood  
flow pathway directly from a heart chamber through a  
heart wall to a coronary vessel comprises a coronary  
portion, a myocardial portion and a transition portion.  
The coronary portion is sized to be received within the  
vessel and the coronary portion is sized to pass through

the myocardium. The transition portion connects the  
coronary portion and the myocardial portion, and de-  
fines an opening that permits bending between these  
portions. The myocardial portion includes a lining for  
controlling tissue growth and an agent to limit thrombus  
formation.

FIG. 1



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**Description****BACKGROUND OF THE INVENTION****1. Field of the Invention**

**[0001]** This invention pertains to an implant for passing blood flow directly between a chamber of the heart and a coronary vessel. More particularly, this invention pertains to such an implant with an enhance design for promoting a healed layer of cells on an interior of the implant.

**2. Description of the Prior Art**

**[0002]** Commonly assigned U.S. Pat. No. 5,755,682 issued May 26, 1998 and commonly assigned and co-pending U.S. Patent Application Serial No. 08/882,397 filed June 25, 1997, entitled "Method and Apparatus for Performing Coronary Bypass Surgery", and filed in the name of inventors Mark B. Knudson and William L. Giese (published as PCT International Application Publication No. WO 98/06356) both teach an implant for defining a blood flow conduit directly from a chamber of the heart to a lumen of a coronary vessel. In one embodiment, an L-shaped implant is received within a lumen of a coronary artery and passed through the myocardium to extend into the left ventricle of the heart. The conduit is rigid and remains open for blood flow to pass through the conduit during both systole and diastole. The conduit penetrates into the left ventricle in order to prevent tissue growth and occlusions over an opening of the conduit. The '682 patent and '397 application also describe an embodiment where a portion of the implant passing through the heart wall is an open structural member lined by polyester (e.g., Dacron). A further embodiment discloses a portion of the implant in a coronary vessel as being an open cell, balloon-expandable stent.

**[0003]** U.S. Pat. No. 5,429,144 to Wilk dated July 4, 1995 teaches implants which are passed through the vasculature in a collapsed state and expanded when placed in the myocardium so as not to extend into either the coronary artery or the left ventricle. The described implants close once per cycle of the heart (e.g., during diastole in the embodiment of Figs. 7A and 7B or during systole in the embodiment of Figs. 2A and 2B). Either of these two designs may be lined with a graft.

**[0004]** Commonly assigned and co-pending U.S. patent application Serial No. 08/944,313 filed October 6, 1997, entitled "Transmyocardial Implant", and filed in the name of inventors Katherine S. Tweden, Guy P. Vannen and Thomas L. Odland, teaches an implant such as that shown in the aforementioned '397 application and '682 patent with an enhanced fixation structure. The enhanced fixation structure includes a fabric surrounding at least a portion of the conduit to facilitate tissue growth on the exterior of the implant.

**[0005]** PCT International Application Publication No.

WO 98/08456 describes a protrusive stent to form a passageway from the heart to a coronary vessel. The stent is described as wire mesh or other metal or polymeric material and may be self-expanding or pressure expandable. The application describes the stent may be covered by a partial or complete tubular covering of material including polyester, woven polyester, polytetrafluoroethylene, expanded polytetrafluoroethylene, polyurethane, silicone, polycarbonate, autologous tissue and xenograft tissue.

**[0006]** Biocompatibility is an important design feature. Solid metal implants are formed of material (e.g., titanium or pyrolytic carbon) with low incidents of thrombus and platelet activation. While such materials are proven in use in a wide variety of products (e.g., heart valve components), they do not facilitate full healing. By "healing", it is meant that over time, the patient's cells grow over the material of the implant so that blood flowing through the implant is exposed only (or at least primarily) to the patient's cells rather than to a foreign material.

**SUMMARY OF THE INVENTION**

**[0007]** According to a preferred embodiment of the present invention, a transmyocardial implant is disclosed for establishing a blood flow path through a myocardium between a heart chamber and a lumen of a coronary vessel residing on an exterior of the heart. The implant includes a coronary portion sized to be received with the vessel. A myocardial portion is sized to pass through the myocardium into the heart chamber. A transition portion connects the coronary and myocardial portions for directing blood flow from the myocardial portion and into the coronary portion. The coronary portion and the myocardial portion have an open construction for permitting tissue growth across a wall thickness of the coronary portion and the myocardial portion. The myocardial portion includes an agent for controlling the coagulation cascade and platelet activation, and promoting healing.

**BRIEF DESCRIPTION OF THE DRAWINGS****[0008]**

FIG. 1 is a side-elevation view of a transmyocardial implant according to the present invention shown in place defining a blood flow path from a left ventricle to a coronary artery;  
 Fig. 2 is a cross-sectional view of the implant of Fig. 1;  
 Fig. 3 is a view of an alternative embodiment of the implant of Fig. 1 illustrating a portion of the implant expandable within a coronary artery;  
 Fig. 4 is a view similar to Fig. 3 showing a transition portion of open cell construction;  
 Fig. 5 is a side section view of an alternative embodiment of Fig. 3 showing a balloon catheter ad-

mitted into the implant through an access port; and Fig. 6 is a side sectional view of an expandable implant with a balloon catheter removable through a myocardial portion of the catheter.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

[0009] With initial reference to FIG. 1, a conduit 10 is shown in the form of an L-shaped tube. The conduit 10 may be formed of titanium or other biocompatible material. The material of the conduit 10 is preferably radially rigid material in order to withstand contraction forces of the myocardium. By way of non-limiting example, the tube will have an outside diameter  $D_o$  of about 3 millimeters and an internal diameter  $D_i$  of about 2.5 millimeters to provide a wall thickness of about .25 millimeters.

[0010] The tube 10 has a coronary portion 12 sized to be received within the lumen of a coronary vessel such as the lumen 80 of a coronary artery 82 distal to an obstruction 81 as illustrated in Fig. 1. The conduit 10 has a myocardial portion 14 extending at a right angle to the axis of portion 12. The myocardial portion 14 is sized to extend from the coronary artery 82 directly through the myocardium 84 and protrude into the left ventricle 83 of a patient's heart.

[0011] The coronary portion 12 has a first opening 16. The myocardial portion 14 has a second opening 18 in communication with an interior 20 of the implant 10. Therefore, blood can freely flow through the implant 10 between the left ventricle 83 and the lumen 80 of the coronary artery 82. Blood flows axially out of opening 16 parallel with the axis of lumen 80.

[0012] The longitudinal axis of the coronary portion 12 is aligned with the axis of the lumen 80. Sutures 24 secure the artery 82 to the coronary portion 12. The proximal portion 82a of the coronary artery is ligated by sutures 85.

[0013] The coronary and myocardial portions 12, 14 have an open lattice construction 12a, 14a to define a plurality of open cells 12b, 14b extending through the wall thickness of the implant 10. Preferably, the coronary and myocardial portions 12, 14 are joined by a transition portion 13 in a 90° bend between portions 12, 14. While transition portion 13 can have an open lattice construction as portions 12, 14, transition portion 13 will preferably have smaller open areas in such an open construction or, as illustrated, will be of solid construction. Such construction permits the transition portion to deflect high velocity blood flows from the myocardial portion 14 into the coronary portion 12. A lattice construction with large open cells in the transition portion could result in the high velocity flow damaging tissue (not shown) overlying the transition portion.

[0014] Any one or all of the coronary portion 12, transition portion 13 and myocardial portion 14 could be formed in final size as rigid units or could be formed in small diameter sizes which are subsequently expanded to full size. For example, Fig. 3 illustrates a coronary

portion 12' which is formed tapering from the transition portion 13' to a reduced diameter open end 16'. The taper permits ease of insertion into a coronary artery. Following such insertion, the tapered coronary portion 12'

5 may be expanded to full size illustrated by the phantom lines in Fig. 3. Such expansion can be performed using balloon-tipped catheters as is conventional in stent angioplasty. A collapsed and subsequently expanded implant 10 where all portions 12, 13 and 14 are expanded 10 can permit use as a percutaneously deployed implant. The present drawings illustrate a presently preferred 15 surgically deployed implant. In the surgical application, the artery 82 is ligated. The implant 10 is passed through the epicardium and myocardium on a side of the artery 82.

[0015] Fig. 5 illustrates a balloon 100 placed in a tapered coronary portion 12. A lead 102 from the balloon 100 is passed through an opening 113' in the transition portion 13'. The opening 113' can be closed with a plug 20 115' after the balloon 100 and lead 102 are withdrawn through the opening 113'. Alternatively, in a transition portion 13" with open cell construction (Fig. 4), the balloon lead can be passed through the openings of the transition portion 113". Fig. 6 illustrates passing the lead

25 102 through opening 18 of the myocardial portion. The lead 102 can be pulled upwardly from the exterior of the heart to remove the balloon 100. Alternatively, the lead 102 can be pulled through a catheter (not shown) adjacent end 18 in the left ventricle.

[0016] In either percutaneous or surgical implants, a 30 flexible transition portion 13 (as would be achieved with a stent lattice construction) permits relative articulation between the coronary and myocardial portions 12, 14 to ensure the coronary portion is axially aligned with the

35 myocardium 80. Absent such articulation, such axial alignment is achieved by accurately controlling the position of the myocardial portion 14 such that the coronary portion 12 is axially aligned with the lumen 80 following implantation.

[0017] The open cell construction of the coronary and myocardial portions 12, 14 permit tissue growth through the open cells 12c, 14c following implant. The healing procedure in the coronary portion 12 is the same as that in coronary stents. Vascular endothelial cells grow over 40 to coat the structural material 12a of portion 12.

[0018] In portion 14, myocardial tissue, if not obstructed, will grow through the cells 14c. Furthermore, the myocardium is highly thrombogenic. Therefore, uncontrolled contact between the myocardium 82 and the implant interior 20 can result in thrombosis of the implant 10. Further, it is believed that the epicardium (i.e., outer 50 layer of the myocardium) has a greater density of myocardial growth cells which contribute to healing.

[0019] To control growth in the myocardial portion 14, a liner 30 is provided in the myocardial portion 14. The liner 30 is any porous material for accepting tissue growth and, preferably, is a polyester fabric (e.g., Dacron). The porous liner 30 has interstitial spaces smaller

than the open cells 12c, 14c. The liner 30 is shown on an interior of the myocardial portion 14 but could also or alternatively surround the exterior.

[0020] The liner 30 has an upper end 32 secured through any suitable means (e.g., sutures not shown) to the upper end of the myocardial portion 14. A lower end 34 is folded over the opening of the myocardial portion 14 and secured to the exterior of the portion 14 by sutures 36. The myocardial portion 14 is sized to protrude into the left ventricle 83 with only the folded over liner material exposed to the interior of the left ventricle 83.

[0021] The liner 30 acts as a porous substrate into which tissue may grow. To prevent thrombus, the liner 30 is impregnated with an agent for controlling coagulation cascade and platelet activation and adhesion. An example of such an agent is heparin but could be any anticoagulant or anti-platelet. Also, an agent such as a basic fibroblast growth factor could be used to accelerate healing.

[0022] The agent permits structural cells to grow on the liner by limiting thrombus formation which, uncontrolled, would occlude the implant. Due to the open construction, the structural, healing cells of the epicardium can grow onto the liner. Subsequently, endothelial cells can grow on the structural cells.

[0023] Therefore, the structure described promotes a three-stage healing process:

1. the drug agents control healing by minimizing coagulation and platelet activation which would otherwise be stimulated by agents from the myocardium; and
2. structural cells grow into and on the liner 30 now lined with the thrombus to initially heal and form a vascular bed; and
3. endothelial cells grow over the structural cells.

[0024] In the transition portion 13, an open cells structure will permit tissue growth as in the coronary portion 12. Such growth may also occur in the solid construction. Alternatively, the liner 30 can be extended into the transition portion 13. Additionally, the open cell structure in the transition portion 13 can permit articulation between the coronary portion and the myocardial portion. Such a structure is shown in Fig. 4. The open transition portion 13" is formed by a coil 13a" between the coronary portion 12" and the myocardial portion 14". This structure permits bending at the transition portion. As a result, the coronary portion can be axially aligned in the artery without first accurately positioning the myocardial portion.

[0025] Having disclosed the present invention in a preferred embodiment, it will be appreciated that modifications and equivalents may occur to one of ordinary skill in the art having the benefits of the teachings of the present invention. It is intended that such modifications shall be included within the scope of the claims appended hereto. For example, the liner 30 can take many con-

structions including PTFE, expanded-PTFE, polyurethane, polypropylene or any biologically compatible paving material or natural tissue. Further, restenosis of the coronary portion 12 can be prevented with radioactivity therapy (such as providing the coronary portion with a short half-life beta emitter). Also, the liner 30 may be either a resorbable or non-resorbable material. Genetically engineered cells can be transformed to secrete anticoagulants and other agents to keep the blood fluid (such as tissue plasminogen activator and smooth muscle cells altered to express nitric acid).

## Claims

1. A transmyocardial implant for defining a blood flow pathway directly from a heart chamber through a heart wall to a coronary vessel, the implant comprising:
  - a coronary portion sized to be received within the vessel;
  - a myocardial portion sized to pass through the myocardium; and
  - a transition portion connecting the coronary portion and the myocardial portion, the transition portion defining an opening permitting bending between the coronary portion and the myocardial portion;

wherein the myocardial portion includes a lining for controlling tissue growth in the myocardial portion, and

wherein the myocardial portion includes an agent for limiting thrombus formation.
2. The implant according to claim 1, wherein the lining has a length substantially equal to a width of the heart wall.
3. The implant according to claim 1, wherein an axis of the coronary portion forms an angle with an axis of the myocardial portion.
4. The implant according to claim 1, wherein the myocardial portion is sized to extend into the heart chamber.
5. The implant according to claim 1, wherein the coronary portion and the myocardial portion are extendable.
6. The implant according to claim 1, wherein the coronary portion is expandable from a first diameter to an enlarged second diameter.
7. The implant according to claim 1, wherein the myocardial portion is expandable from a first diameter

to an enlarged second diameter.

8. The implant according to claim 1, further comprising an agent for encouraging healing.

9. The implant according to claim 8, wherein the agent for encouraging healing is a growth factor.

10. The implant according to claim 1, wherein the lining contains the agent.

11. The implant according to claim 1, wherein the agent is heparin.

12. The implant according to claim 1, wherein the agent is an anti-coagulant.

13. The implant according to claim 1, wherein the agent is an anti-platelet.

14. The implant according to claim 1, wherein the lining includes a polyester fabric.

15. The implant according to claim 1, wherein the lining includes PTFE.

16. The implant according to claim 1, wherein the lining is on an interior portion of the myocardial portion.

17. The implant according to claim 1, wherein the transition portion includes a coil.

18. A conduit for providing blood flow directly from a heart chamber to a coronary vessel, comprising

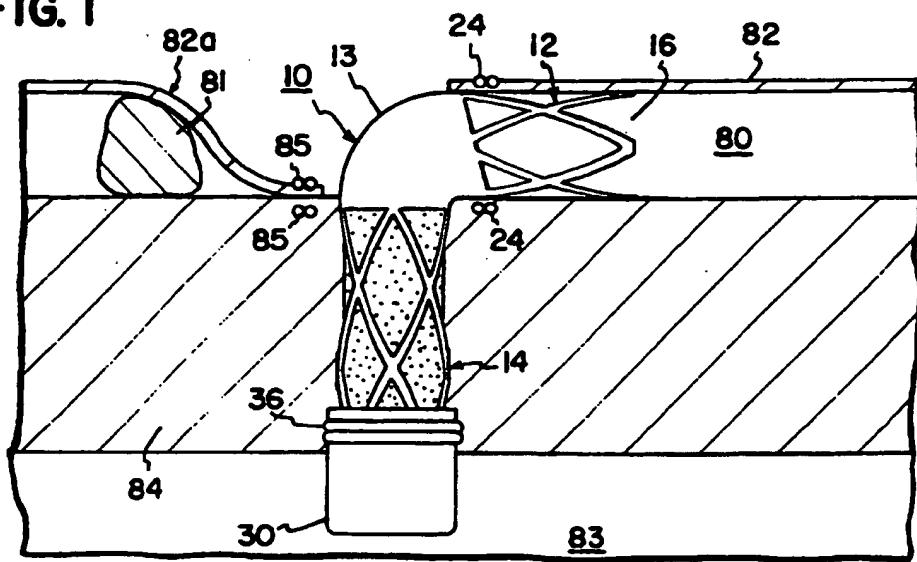
a stent that includes a configuration having sufficient radial strength to resist deformation from contractile forces experienced during a cardiac cycle and remain patent when implanted in a myocardial site and having sufficient flexibility in a compressed state to permit passage to myocardial site, a covering on an inner surface portion and outer surface portion of the stent, and an agent that limits thrombus formation.

19. The conduit of claim 18, wherein the covering includes expandable polytetrafluoroethylene.

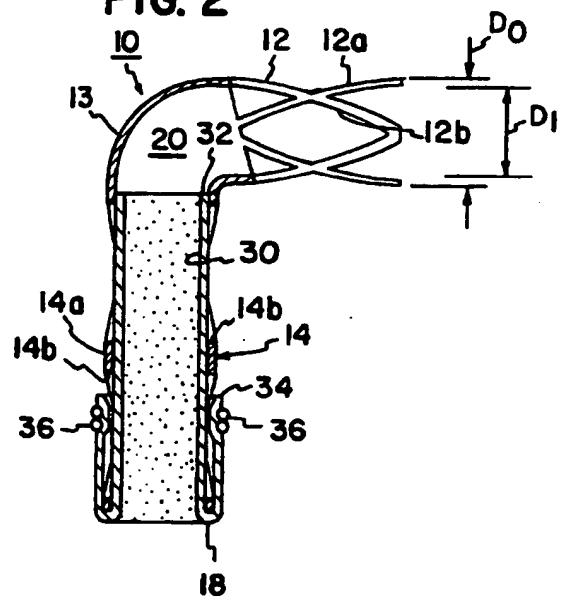
20. The conduit of claim 18, wherein the covering includes a material chosen from polytetrafluoroethylene, expandable polytetrafluoroethylene, polyurethane, polypropylene, a biologically compatible paving material, natural tissue, and a polyester fabric.

21. The conduit of claim 18, wherein the agent includes heparin.

**FIG. 1**



**FIG. 2**



**FIG. 3**

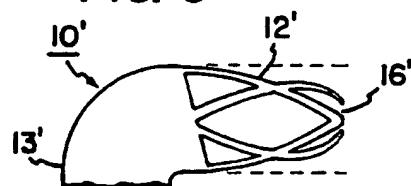


FIG. 6

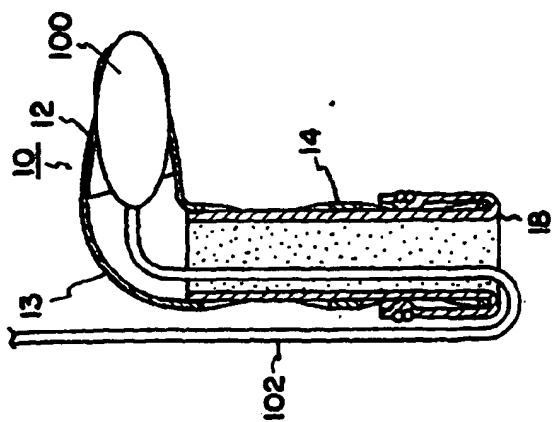


FIG. 5

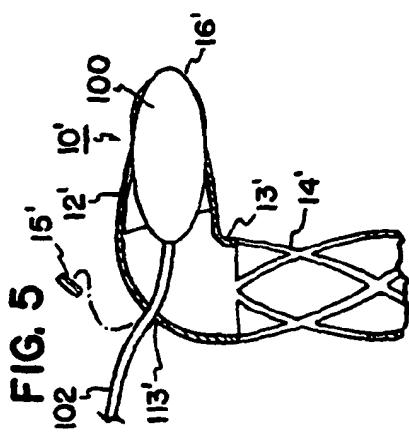


FIG. 4

